Agricultural Systems 155 (2017) 136–146

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Review

# Social and ecological analysis of commercial integrated crop livestock systems: Current knowledge and remaining uncertainty

R.D. Garrett[a,*], M.T. Niles[b,c], J.D.B. Gil[a,d], A. Gaudin[e], R. Chaplin-Kramer[f], A. Assmann[g], T.S. Assmann[h], K. Brewer[e], P.C. de Faccio Carvalho[i], O. Cortner[a], R. Dynes[j], K. Garbach[k], E. Kebreab[l], N. Mueller[m], C. Peterson[e], J.C. Reis[n], V. Snow[j], J. Valentim[o]

[a] Department of Earth and Environment, Boston University, 685 Commonwealth Avenue, Boston, MA 02215, USA
[b] Department of Nutrition and Food Sciences, University of Vermont, 350 Carrigan Wing, 109 Carrigan Drive, Burlington, VT 05405, USA
[c] Food Systems Program, University of Vermont, 350 Carrigan Wing, 109 Carrigan Drive, Burlington, VT 05405, USA
[d] Plant Production Systems, Wageningen University, P.O. Box 430, 6700 AK Wageningen, The Netherlands
[e] Department of Plant Sciences, University of California, Davis, 1 Shields Ave, Davis, CA 95616, USA
[f] Natural Capital Project, Stanford University, 371 Serra Mall, Stanford, CA 94305, USA
[g] Agricultural Institute of Paraná, Rod. BR 158, 5517 SR, CEP 85501-970, Pato Branco, PR, Brazil
[h] Departamento of Agronomy, Federal University of Technology-Paraná, Via do Conhecimento, Km 1, CEP 85503-390 Pato Branco, PR, Brazil
[i] Departamento de Plantas Forrageiras e Agrometeorologia, Universidade Federal do Rio Grande do Sul, Av Bento Gonçalves 7712, Porto Alegre, RS 91540-000, Brazil
[j] AgResearch, Lincoln, Private Bag 4749, Christchurch 8140, New Zealand
[k] Point Blue Conservation Science, 3820 Cypress Dr. #11, Petaluma, CA 94954, USA
[l] Department of Animal Science, University of California, Davis, CA 95616, USA
[m] Department of Earth System Science, University of California, Irvine, Croul Hall, Irvine, CA 92697, USA
[n] Embrapa Agrossilvopastoral, Sinop, MT, Brazil
[o] Agroforestry Research Center of Acre, Embrapa Acre, Rio Branco, AC CEP 70770-901, Brazil

## ARTICLE INFO

*Keywords:*
Food systems
Agroecology
Sustainable agriculture
Mixed crop livestock
Ecosystem services

## ABSTRACT

Crops and livestock play a synergistic role in global food production and farmer livelihoods. Increasingly, however, crops and livestock are produced in isolation, particularly in farms operating at the commercial scale. It has been suggested that re-integrating crop and livestock systems at the field and farm level could help reduce the pollution associated with modern agricultural production and increase yields. Despite this potential, there has been no systematic review to assess remaining knowledge gaps in both the social and ecological dimensions of integrated crop and livestock systems (ICLS), particularly within commercial agricultural systems. Based on a multi-disciplinary workshop of international experts and additional literature review, we assess the current knowledge and remaining uncertainties about large-scale, commercial ICLS and identify the source of remaining knowledge gaps to establish priorities for future research. We find that much is understood about nutrient flows, soil quality, crop performance, and animal weight gain in commercial ICLS, but there is little knowledge about its spatial extent, animal behavior or welfare in ICLS, or the tradeoffs between biodiversity, pest and disease control, greenhouse gas (GHG) mitigation, and drought and heat tolerance in ICLS. There is some evidence regarding the economic outcomes in commercial ICLS and supply chain and policy barriers to adoption, but little understanding of broader social outcomes or cultural factors influencing adoption. Many of these knowledge gaps arise from a basic lack of data at both the field and system scales, which undermines both statistical analysis and modeling efforts. Future priorities for the international community of researchers investigating the tradeoffs and scalability of ICLS include: methods standardization to better facilitate international collaborations and comparisons, continued social organization for better data utilization and collaboration, meta-analyses to answer key questions from existing data, the establishment of long term experiments and surveys in key regions, a portal for citizen science, and more engagement with ICLS farmers.

* Corresponding author.
*E-mail address:* rgarr@bu.edu (R.D. Garrett).

http://dx.doi.org/10.1016/j.agsy.2017.05.003
Received 17 December 2016; Received in revised form 2 May 2017; Accepted 8 May 2017
0308-521X/ 

## 1. Introduction

The last century has brought remarkable transformation in global food systems via the proliferation of non-draught powered farm machinery, improvements in plant and animal genetics, the invention of synthetic fertilizers, and increased trade (Busch and Bain, 2004; Foley et al., 2011). While many of these changes have contributed to increasing global food production, another consequence has been the de-coupling of crop and livestock systems and a loss of agricultural diversity at both the field and territorial (regional) scales in many countries (Naylor et al., 2005). Although these two functional groups of agricultural production worked for hundreds of years in a synergistic capacity on rural landscapes throughout the world (FAO, 2010), crops and livestock are increasingly produced in isolation, separated in some cases by great distances (Peyraud et al., 2014), particularly in commercial-scale farms - farms that sell a majority of their production (Robinson et al., 2011). This de-coupling has engendered major changes in production practices and agricultural supply chains and numerous social and environmental externalities (Naylor et al., 2005). It has been suggested that re-integrating crop and livestock systems at the field or territorial level (by co-locating them in space and over time) (Bell and Moore, 2012) could help solve many of the social, economic, and environmental challenges that our global food system now faces (FAO, 2010; Martin et al., 2016; Wilkins, 2008). Some governments have even developed programs and policies to promote the re-integration of commercial scale crop and livestock systems in their countries (e.g. Australia's Grain and Graze program (http://lwa.gov.au/programs/grain-and-graze) and Brazil's National Crop-Livestock-Forestry Integration Policy (Law 12,805/13).

The integration of crop and livestock systems may occur in a variety of forms. Examples of field level integration of crop and livestock systems include: i) grazing livestock on crops, crop residues, or forage cover crops, ii) phase farming, i.e., rotating pastures and cropland over several years, and iii) grazing of understory vegetation in vineyards or orchards. Examples of territorial integration include: i) cooperative arrangements between different farms to allow temporary grazing on crop residue, ii) regional planning to match supply and demand for livestock feed, and iii) trading animal wastes and crop residues between farms (Martin et al., 2016).

Understanding the interactions between dynamic configurations of crops, forages, and livestock and the broader natural and human systems in which they are embedded requires models and data that span many disciplines and scales. Yet, research on social and ecological outcomes of different forms of ICLS, particularly within commercial farming systems (as opposed to subsistence farming systems), remains limited or regionally concentrated, minimizing the capacity to compare across systems and regions and advance a broader understanding about the cost and benefits of ICLS. Due to these research gaps it is hard to take stock of which questions we are currently able to answer with existing data and models, and where substantial capacity needs to be built to address present knowledge gaps and future questions.

For this reason, we convened a meeting of international scientists, practitioners, and modeling experts as part of a National Science Foundation “Science, Engineering, and Education for Sustainability” grant (#1415352). The meeting took place at the University of California, Davis in April, 2015 and was attended primarily by researchers from the two focal countries of the grant: Brazil and the United States, but also participants from other regions where commercial ICLS is also occurring at scale including New Zealand and Europe. During the two-day workshop, we addressed the following questions, which we detail in this paper:

i) What do we currently know about the social and ecological processes in commercial ICLS?
ii) What knowledge about these processes do we lack that prevents us from understanding the likely social and environmental outcomes if ICLS are adopted on a wide scale and the factors that may limit adoption?
iii) What is the source of these knowledge gaps?
iv) What data, models, and analysis should be prioritized to address these knowledge gaps and their sources?

Answers to these questions are necessary to help define priorities for the scientific community, funding agencies, and practitioners to advance ICLS research across multiple disciplines. They can also help set the agenda for more applied work and partnerships among farmers, researchers, and non-profit organizations and help design systems, management options and policies which will help disseminate ICLS across an array of potentially interested communities.

The following paper represents a systematic effort based on the aforementioned workshop and additional literature review to answer these questions, particularly as they pertain to large scale, commercial agricultural systems. To structure our findings, we identified four fields of inquiry relevant to ICLS. These fields of inquiry include:

i) Nutrient flows and crop performance in ICLS;
ii) Animal performance, health, and welfare in ICLS;
iii) Emergent ecosystem properties of ICLS; and
iv) Social benefits and barriers to ICLS adoption.

Based on this review and synthesis we summarize whether major knowledge gaps are due to data or model limitations, or both. We then discuss key priorities to advance research on ICLS in the future based on our analysis.

This work builds on the results of a global consultation on ICLS (FAO, 2010) and several other comprehensive reviews of current knowledge related to ICLS in commercial systems in Australia, Brazil, Europe, and the United States (Bell and Moore, 2012; Bonaudo et al., 2014; de Moraes et al., 2014a; Lemaire and Franzluebbers, 2013; Martin et al., 2016; Peyraud et al., 2014; Russelle et al., 2007; Sulc and Franzluebbers, 2014). Most of these reviews focus on the benefits of ICLS within a single geographic region, although some also touch on challenges for their adoption. We extend these reviews by synthesizing research on commercial ICLS between regions and including more information on the social aspects of ICLS. More importantly, we use this synthesis of current knowledge to highlight remaining knowledge gaps and identify future research priorities.

## 2. ICLS in the focal regions

This paper focuses on current knowledge of ICLS in Australia, Brazil, France, New Zealand, and the United States due to our interest in larger scale, commercial agricultural systems and the existence of sufficient prior research on ICLS in these regions. There are likely other countries (i.e. Canada) where commercial ICLS can be found, but there is little existing research from these regions (a major knowledge gap in and of itself).

Within the focal regions, ICLS systems take a variety of forms but typically involve cereals and sheep or beef cattle (Table 1). Large farms ($>$ 20 ha) are the most common and dominate the landscape (except for Brazil where large farms comprise 40% of the farms but 95% of the area) (Adamopoulos and Restuccia, 2014; Lowder et al., 2016). In all regions, large scale monocultures and/or continuous pasture systems contribute greatly to the country's major environmental challenges, including greenhouse gas emissions, water and air pollution, salinization, and biodiversity loss (Lapola et al., 2013; Monaghan et al., 2007; Rengasamy, 2006; Stoate et al., 2001; Tilman et al., 2002).

Despite the commonality of large farm sizes, the focal regions span a range of social (policy, culture, and economic) and ecological (climate, topography, and vegetation) contexts (Garrett et al., 2017; Peyraud et al., 2014), which makes their comparison helpful for understanding how differing social and ecological contexts affect outcomes in com-